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Volumetric, planar and linear airway comparison after maxillomandibular advancement surgery

Deepa Vyas
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Volumetric, Planar and Linear Airway Comparison after Maxillomandibular Advancement Surgery

Deepa Vyas, D.M.D.

A THESIS

Submitted to:
The School of Dentistry at West Virginia University
In partial fulfillment to the requirements
for the degree of

Master of Science In Orthodontics

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Chris Martin, D.D.S., M.S.
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West Virginia University
Department of Orthodontics

Morgantown, West Virginia
2014

Keywords: maxillomandibular advancement, sleep apnea, cbct
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ABSTRACT

Volumetric, Planar and Linear Airway Comparison After Maxillomandibular Advancement Surgery

Deepa Vyas, D.M.D., Peter Ngan, D.M.D., Chris Martin, D.D.S., M.S., Bryan Weaver, D.D.S., M.D., Mary E. Burns D.M.D. and Erdogan Gunel, Ph.D.

Background and Objectives: Treatment of sleep apnea can be accomplished using both non-surgical and surgical methods. Surgical treatment is further classified into phase I and II surgery. When phase I treatment fails, orthognathic surgery is judged to be the subsequent step in treating these patients. Orthognathic surgery is considered phase II treatment and can consist of a maxillomandibular advancement (MMA)¹⁻¹¹. Until recently, most of the data gathered on patients how have had a maxillomandibular advancement has been completed using lateral cephalograms. The rationale for this study is to gain a better understanding of the alteration in linear, planar and volumetric posterior airway space following double-jaw advancement surgery with a counter-clockwise rotation of the occlusal plane.

Methods: A total of 28 subjects pre- and post-surgical CBCT scans were evaluated. All of the individuals underwent a maxillomandibular advancement with a counterclockwise rotation of the occlusal plane. All DICOM files were analyzed using Dolphin 3D Imaging 11.5, licensed to West Virginia University Department of Orthodontics. The CBCT volume was used to create right lateral cephalograms which were then used for linear cephalometric measurements. The 3D volume was also utilized to find cross-sectional measurements from axial slices taken from the cone-beam images at specific points: PNS, CV1, CV2 and CV3. Finally, CBCT images were used to find volume measurements at explicit regions along the posterior airway space. Data was analyzed using a matched-pair test.

Results: When all subjects were grouped together the p-value for the change in all variables was <0.05 . This indicates that there was a statistically significant change in all variables regardless of the method used to evaluate pre- and post-surgery changes. It also suggests that although CBCT is a valuable tool to evaluate airway change, cephalometric radiographs can be used to determine whether change in PAS is significant when it pertains to maxillomandibular advancement surgery.

Conclusions: The maxillomandibular advancement procedure with or without genioplasty illustrated great increases in posterior airway space in both 2-dimensional and 3-dimensional analyses. However, more information was available in regards to site of airway obstruction when utilizing the 3D data in comparison to 2D. Patients with obstructive sleep apnea should be presented with the option of MMA surgery as a treatment option if CPAP is not tolerated or other therapies have failed.

DEDICATIONS

To my husband and best friend, **Brandon Kiger**. Thank you for being my rock during stressful times. Your knowledge, organizational skills and upbeat attitude are what kept me afloat when I was overwhelmed with worry. I'm so glad we have the rest of our lives to support each other.

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CHAPTER 1: INTRODUCTION

Background

The official definition of obstructive sleep apnea according to the American Academy of Sleep Medicine is as follows: recurrent episodes of partial or complete upper airway obstruction during sleep despite ongoing inspiratory effort¹².

According to the United States Department of Health, more than 12 million people are affected by obstructive sleep apnea and many more individuals go undiagnosed. In fact, 1 in 5 adults have a form of mild sleep apnea; while 1 in 15 have moderate severity OSA. According to the Wisconsin cohort study, 93% of women and 82% of men have undiagnosed moderate to severe sleep apnea¹³. Sleep apnea can affect all age ranges from children to adults¹². It has been documented that 3.2 to 12.1% of children habitually snore and anywhere from 0.3 to 10.3% have some form of OSA^{4,14}.

In adults, the symptoms that are often seen in relation of obstructive sleep apnea are the following: excessive daytime sleepiness (EDS), morning headaches, dry mouth, sore throat, snoring, gastroesophageal reflux, and sexual dysfunction. Excessive daytime sleepiness has been shown to cause an increase in motor vehicle accidents^{1,2,5,13,15}. In children, OSA manifests as behavioral problems that are many times misdiagnosed as attention deficit hyperactivity disorder (ADHD)¹⁴. The importance of identification and treatment of this syndrome for both children and adults is of major concern, since if OSA is left untreated it can lead to severe complications in a person's overall health^{2,3,12,14-16}.

Treatment of sleep apnea can be accomplished using both intraoral and extraoral appliances as well as surgery. The gold standard to treat sleep apnea is through the use of a continuous positive airway pressure (CPAP) machine¹². The CPAP machine works by using air pressure created by the device to open the airway during sleep, thus preventing collapse^{3,4,12}. Although this machine is very effective in treating patients with sleep apnea, it often has unwanted side effects and therefore compliance is low. Mild to moderate forms of sleep apnea can be treated by dental professionals by using devices which can open the airway by either protruding the mandible or repositioning the tongue in a more forward position^{5,12,14,15}.

When non-surgical approaches are not tolerated well by patients, a surgical approach to clear the obstruction is warranted. The most common surgical approaches include, but are not limited to: nasal reconstruction, uvulopalatopharyngealplasty (UPPP), or orthognathic surgery³. Nasal reconstruction and UPPP surgical approaches are referred to as phase I surgical treatment, but are often times not successful in management of OSA. When phase I treatment fails, orthognathic surgery is judged to be the subsequent step in treating these patients. Orthognathic surgery is considered phase II treatment and can consist of a maxillomandibular advancement (MMA)¹⁻¹¹.

Statement of the Problem

Until recently, most of the data gathered on patients who have had a maxillomandibular advancement has been completed using lateral cephalograms. Although this tool is useful in identifying pharyngeal airway space (PAS) and possible pathologies, it is only a 2-dimensional representation of a 3-dimensional structure. Often times, an image of the PAS seen on a lateral

cephalogram can underestimate the true obstruction, since it would not represent the true volumetric airway of a given subject^{17,18}. However, a relatively new imaging technology that is able to capture 3-dimensional images has become commercially available on the market¹⁸. This new technology is known as cone-beam computed tomography (CBCT). CBCT offers dental professionals an opportunity to evaluate a patient's airway in 3-dimensions while only exposing them to a minimum amount of radiation when compared to other medical CTs. This form of radiography has been documented to reliably provide an accurate representation of volumetric airway dimensions in an efficient manner that is considered superior to images obtained from cephalograms alone¹⁷⁻²¹. This study will determine if there is a correlation in the reliability of airway measurements using both lateral cephalograms and CBCT images obtained both before and after maxillomandibular advancement surgery.

Significance of Problem

While CBCT is the preferred method for evaluating pharyngeal airway space, there has not been extensive research published using this technology when compared to research of PAS utilizing lateral cephalograms¹⁸. Even less research is available in the area of 3-dimensional airway analysis following orthognathic surgery. Therefore, more information, from a 3-dimensional perspective is needed to understand the effects of maxillomandibular advancement. Determining which segment of the airway is most affected by MMA surgery can help in determining if a patient's sleep apnea can be alleviated by surgery or if perhaps another method of treatment may be more appropriate.

Purpose of Study

The rationale for this study is to gain a better understanding of the alteration in linear, planar and volumetric posterior airway space following double-jaw advancement surgery with a counter-clockwise rotation of the occlusal plane. In addition, this study will investigate whether there is a correlation between 2-dimensional cephalometric and 3-dimensional cross-sectional measurements at specific sites along the airway. According to Abramson et al., “an association between 3D upper airway anatomy and the presence and severity of OSA has been reported²². It is well known that MMA surgery decreases airway resistance and increases airway patency^{2,4,8,11,16,22-34}. However, the specific region of the airway that shows the most increase post maxillomandibular advancement surgery has yet to be distinguished. Therefore, this study will aim to identify which segment of the airway increases the most after MMA surgery. These findings will help to identify which group of individuals will benefit the most from phase II surgery dependent on where their region of most constriction occurs.

Null Hypothesis

1. There is no significant difference in total airway volume before and after maxillomandibular surgery.
2. There is no significant difference in airway volume before and after maxillomandibular advancement surgery in the retropalatal region
3. There is no significant difference in airway volume before and after maxillomandibular advancement surgery in the oropharyngeal region.

4. There is no significant difference in airway volume before and after maxillomandibular advancement surgery in the hypopharyngeal region.
5. There is no significant difference in cross-sectional area before and after maxillomandibular advancement surgery at the level of the posterior nasal spine (PNS).
6. There is no significant difference in cross-sectional area before and after maxillomandibular advancement surgery at the level of the 1st cervical vertebra (CV1).
7. There is no significant difference in cross-sectional area before and after maxillomandibular advancement surgery at the level of the 2nd cervical vertebra (CV2).
8. There is no significant difference in cross-sectional area before and after maxillomandibular advancement surgery at the level of the 3rd cervical vertebra (CV3).
9. There is no correlation between cephalometric linear measurements and 3-dimensional cross-sectional measurements.

Definition of Terms

- 2D - Two Dimensional (2-Dimensional)
    - Refers to objects that have dimensions of height and width, but do not have depth.
- Two dimensional objects such as radiographs can be evaluated according to

height and width, but do not provide an accurate representation of 3-dimensional structures with have a transverse dimension as well.

- 3D – Three Dimensional (3-Dimensional)
  - Refers to objects that have dimensions of height, width and depth. Three dimensional objects better represent actual anatomic structures as long as there is a 1 to 1 ratio.

- Central Sleep Apnea

A type of sleep disordered breathing (SDB), in which there is no obstruction of the airway, but rather a lack of respiratory effort due to failure of the brain to signal muscles that are involved in breathing¹².

- Cephalogram
  - Synonym for cephalometric radiograph
- Cephalometric Analysis
  - A series of measurements based on a radiograph of the head (cephalogram), to determine facial morphology and distinguish dental and skeletal characteristics which are usually compared to norms.
- Cephalometric Radiograph
  - A radiograph of the head and neck that is a 2-dimensional representation of these structures.
- Computed tomography (CT)
  - A series of radiographs (flat, two-dimensional grayscale images) that are analyzed and rendered via computer to produce a three-dimensional volumetric or surface mapped image.

- Cone Beam Computed Tomography (CBCT)
  - A computed tomography scan utilizing an x-ray beam in the shape of a cone to provide images of bony structures. Data is captured by a flat receiver that detects pulses of cone shaped beam radiation. The result is a stack of two-dimensional grayscale images of the anatomy which can be rendered into volumetric data to visualize anatomical structures in three dimensions. Also known as Cone Beam Volumetric Tomography (CBVT)
- Digital Imaging and Communications in Medicine (DICOM)
  - DICOM is a standard for handling, storing, printing, and transmitting medical images. It includes a file format in which data from volumetric radiographs are stored.
- Frankfort Horizontal Plane
  - A horizontal plane represented in profile by a line between the lowest point on the margin of the orbit and the highest point on the margin of the auditory meatus.
- Landmark
  - A fixed, reproducible (anatomical) point of reference on a radiograph.
- Nasopharynx
  - The uppermost portion of the airway, mainly the nose. It begins with the nares, where air enters the nose, and extends back to the hard palate at the superior portion of the soft palate. This includes the nasal septum and the nasal turbinates.
- Obstructive Sleep Apnea
  - A sleep disorder that occurs when a person's breathing is interrupted during sleep. It is caused by a narrowing or blocking of the airway due to the collapse of soft

tissues in the pharynx and retraction of the genioglossus muscle allowing the tongue to slide further posterior than normal, thus blocking the airway.

- Oropharynx
  - Includes the oral cavity, beginning with the back portion of the mouth and extending rearward to the base of the tongue. This segment of the posterior pharyngeal wall includes the tonsils. In this area are many muscles, both extrinsic and intrinsic, that control tongue posture: genioglossus, palatoglossus, and the superior longitudinal and transverse muscles of the tongue as examples.
- Referent
  - A variable, reproducible (anatomical) point related to a landmark on a radiograph.
- Resolution
  - The smallest distance between two points at which the viewer can still distinguish the two points as separate entities. Higher resolutions provide finer detail.
- Sievert (Sv)
  - Standard international (SI) unit of radiation dose equivalent. This unit of measure reflects the biological effects of radiation (as opposed to the physical aspects which are characterized by absorbed dose measured in Grays).
- Tomogram
  - A radiograph representing a “slice” or sectioned focal area by moving an x-ray source and the film in opposite directions during exposure. Structures in the focal plane appear sharp, while structures in front of and behind the plane are blurred.
- Velopharynx

- Extends from the hard palate to the inferior tip of the soft palate. Includes the uvula and the uppermost segment of the posterior pharyngeal wall. Major muscles include the tensor palatini and levator palatini, which elevate the soft palate, and the musculus uvulae providing elevation of the uvula.
- Volumetric
  - Visual representation of an image in three dimensional space.
- Voxel
  - The smallest element in building a three-dimensional image. It is similar to a “pixel” in a flat two-dimensional image display. Voxel size is important in defining the resolution of a volumetric image (smaller voxel size = higher resolution). The voxel size of a CBCT image can be as small as 0.16 cubic millimeters while the voxel size of a traditional CT image is 0.32 cubic millimeters.

Assumptions

1. Airway parameters can be accurately and reliably identified using Cone-Beam Computed Tomograph (CBCT) technology.
2. CBCT scans on subjects are taken in centric relation as opposed to centric occlusion.
3. The CBCT scans are of sufficient quality without patient movement introducing artifacts in the scan.
4. The operator has sufficient knowledge of measurement software which is Dolphin 3D version 11.5.

Limitations

1. There are differences in medical history, gender, and ethnicity among the subjects.
2. Measurements are limited to the researcher's ability to accurately operate cone-beam computed tomography images.
3. 3-dimensional scans may have artifacts from subject movements and machine specifications.
4. The study is limited to the subjects in the database of New Hope Orthodontics, which is the private practice of Dr. Mary E. Burns.

Delimitations

1. The skeletal ages of subjects in the sample have a cervical vertebra maturation stage (CVMS) of 4 or greater.
2. One researcher measures and evaluates all data from CBCT scans.
3. All pre-surgical scans are with the surgical splint in place and taken in centric relation.

CHAPTER 2: REVIEW OF LITERATURE

Introduction to Sleep Apnea

Sleep apnea is often first identified by a family member who may observe an episode of sleep disordered breathing such as gasping for air. Sleep apnea does not discriminate, Young et al., estimated that “1 in 5 adults has at least mild OSA and 1 in 15 adults has at least moderate OSA. Sleep apnea can affect anyone at any age, even children”¹³. According to the U.S. Department of Health, 12 to 18 million adults are affected by sleep apnea while many more go undiagnosed³⁵. Risk factors that predispose an individual to OSA include, but are not limited to male gender, increased neck size or small chin/jaw size, those over 40 years of age, airway anatomy and a body-mass index (BMI)^{2,3,8,12}.

Diagnosis of Sleep Apnea

According to the American Academy of Sleep, apnea is pause in breathing that lasts at least 10 seconds. These pauses in airflow can occur several times per hour. On the other hand, hypopnea is defined as a decrease in airflow that persists for at least 10 seconds^{5,12,15}. This is different from apneas in that there still some air that is being exchanged during ventilation. Hypopneas are only considered to be significant if there is at least a 30% reduction in air flow as well as 4% or greater desaturation in oxygen levels^{5,12}.

The Apnea-Hypopnea Index (AHI) is employed to determine the severity of obstructive sleep apnea. In terms of severity, mild OSA is described as an AHI between 5 and 15, with

symptoms of sleepiness. Moderate OSA would be identified if a patient has an AHI between 15 and 30. While severe OSA is diagnosed in individuals that have an AHI greater than 30.

Another system is often used to describe the severity of OSA in individuals. This classification system is known as the respiratory distress index (RDI). RDI measures respiratory event related arousals (RERA). Some studies have shown that RDI is a better indicator for OSA than AHI¹².

Complications Associated with OSA

Individuals with obstructive sleep apnea often experience signs and symptoms that include, but are not limited to: excessive daytime sleepiness (EDS), morning headaches, cognitive impairment, depression, gastroesophageal reflux, sexual dysfunction, dry mouth and sore throat^{3,5,12,14,16}. Other systemic problems associated with OSA are: hypertension, stroke, myocardial infarction and other cardiac abnormalities^{5,12,14,16}.

Types of Sleep Apnea

Sleep disordered breathing (SDB) encompasses a host of disorders that involve pauses in breathing. The two major forms of SDB are: central sleep apnea (CSA) and obstructive sleep apnea (OSA). Central sleep apnea does not involve blockage of the airway, but rather a lack of respiratory effort due to the brain not sending the correct signals to respiratory muscles¹².

Obstructive sleep apnea on the other hand is due to physical blockage of the airway at one or

more regions. OSA results in airflow disruption due to collapse of surrounding tissues in the upper airway. Of these two types of sleep disordered breathing, OSA accounts for more than 85% of sleep apneas, while CSA is less frequent¹².

Non-Surgical Treatment for Sleep Apnea

Non-surgical treatment for OSA can begin with behavioral changes that encourage weight-loss, abstaining from alcohol, antihistamines, smoking, sedatives or change in sleeping position^{5,12,15}. When the above modifications do not produce the significant differences in OSA symptoms, then more aggressive treatment is warranted. Continuous positive airway pressure (CPAP) is currently the gold standard for non-surgical treatment of OSA. CPAP works as a pneumatic stent, opening the upper airway by continuous pressurized air flow. Although this appliance is very effective when used properly, compliance can be as low as 40% due to, “physical discomfort associated with wearing the unit, drying of the nasal and oral mucosal membranes, dislodgement during sleep, noise and the social consequences of using the unit¹”.

Figure 1. CPAP Machine³⁶

When patients cannot tolerate CPAP therapy, oral appliances (OA) can provide an alternative means of treatment. These devices are generally better tolerated than CPAP treatment because they are less cumbersome and can partially alleviate symptoms of obstructive sleep apnea^{12,14,15}. The two most common OA therapies involve tongue retaining devices (TRD) and mandibular advancement devices (MAD). Both of these treatment modalities have been shown to improve show improvements in patients with OSA. The TRD works by creating a suction when the tongue is placed in the bubble. This holds the tongue more anteriorly in hopes of opening the upper airway³⁶.

Figure 2. Tongue Retaining Device³⁶ (TRD)

Mandibular Advancement Devices (MAD) have been shown by several studies to improve airway patency and OSA symptoms, but can have unfavorable dental side effects³⁷. This device holds the mandible more forward thereby increasing the posterior airway space. These devices must be custom made for each patient and adjusted by a dentist in order to be effective.

Figure 3. Mandibular Advancement Appliance³⁶

Surgical Treatment for Sleep Apnea

When non-surgical approaches are not tolerated well by patients, a surgical approach to clear the obstruction is warranted. Surgical treatment for sleep apnea is classified as either phase I treatment or phase II treatment. Phase I treatment is generally considered to be less invasive and is the 1st course of action to permanently alleviate symptoms of OSA. Phase I treatment includes: Nasal reconstruction, uvulopalatopharyngoplasty (UPPP), genioglossus/hyoid suspension and tongue reduction^{3,5}. Nasal obstruction is seen when an individual has a deviated septum, hypertrophic turbinates or nasal valve stenosis. In this case, nasal reconstruction can correct the obstruction and decrease nasal resistance to airflow.

In the case of a retropalatal obstruction, UPPP is the procedure of choice. It was first introduced by Fujita in 1979, but has since been revised⁵. This surgery involves “removal of part of the soft palate, uvula, and tonsils, as well as part of the pharyngeal wall”¹⁵. UPPP continues to be well-accepted even though reviews have reported improvement in less than 50% of patients and total management of OSAS in fewer than 25% of patients. The explanation for the very small success rate may lie in the fact that the UPPP addresses only one location of a multi-site problem^{3,9,11,12}.

Figure 4. UPPP Procedure¹¹.

When phase I treatment fails (UPPP or nasal reconstruction), orthognathic surgery is judged to be the subsequent step in treating patients with obstructive sleep apnea. Orthognathic surgery is categorized as phase II surgery. Maxillomandibular advancement surgery is now the treatment of choice in terms of orthognathic procedures to treat OSA. According to Schendel et al., “the goal of surgical treatment of OSA syndrome is to enlarge the velo-pharyngeal airway by anterior/lateral displacement of soft tissues and musculature by maxillary, mandibular, and possibly, genioglossus advancement”¹⁰.

Figure 5. Maxillomanidbular Advancement Surgery¹¹

Physics of the Airway

The airway is essentially composed soft tissue that is has the potential to collapse when muscles relax during sleep. The likelihood of collapse of the airway increases when persons have the following predispositions: 1) craniofacial abnormalities or 2) large fat deposits which can add extra pressure on the surrounding airway soft tissue¹².

Figure 6. Airway changes with weight gain or craniofacial micrognathia¹²

Traditional Cephalometric Airway Analysis

The most widely used orthodontic airway analysis was derived by McNamara in 1984. This analysis consists of measuring the airway using a 2D cephalometric image. The McNamara analysis utilizes only two measurements taken from a lateral cephalogram to examine the possible airway dysfunction³⁸. However, these values only give information on 2 sites where as airway obstruction can occur at multiple sites and therefore this analysis is not useful in diagnosing OSA in adults.

Figure 7. McNamara Airway Analysis³⁸

Current Questions Still Unanswered

Given that CBCT imaging is a fairly recent technology, there have not been many airway evaluation studies conducted utilizing this technology. The effect on the airway from more than a 2-dimensional perspective is needed. Moreover, a comparison of 2-dimensional versus 3-dimensional analysis of similar regions of the airway is also essential to understand the validity of past studies.

Orthognathic Surgery

Orthognathic surgery is often necessary for individuals that show evidence of jaw discrepancies that cannot be compensated for with orthodontic treatment alone. In this case, surgical procedures can help produce a more harmonious facial balance and optimal occlusion¹⁸. Often when there is a severe antero-posterior discrepancy, the airway can be either improved or get worse.

Airway Changes with Class III Correction

Many patients that present with a class III malocclusion can only be treated with orthognathic surgery. Studies have shown that there is a decrease in the airway following mandibular setback surgery alone³⁹⁻⁴¹. This may due to “inferior repositioning of the hyoid bone and posterior displacement of the tongue and the soft palate. These movements cause anteroposterior and lateral narrowing of the PAS²⁶”.

Therefore, other researchers suggest bimaxillary surgery which consists of a maxillary advancement and mandibular setback, when a severe antero-posterior discrepancy exists⁴²⁻⁴⁵.

Airway Changes with Mandibular Advancement Alone

A cephalometric study by Achilleos et al., suggests that there is long-term increase in airway dimensions after mandibular advancement alone⁴⁶. However, another long-term follow-up study by Eggenesperger et al., indicates that after an initial increase in PAS, there was

significant relapse after mandibular advancement alone⁴⁷. Consequently, the current recommendation for phase II OSA treatment is maxillomandibular advancement surgery as opposed to mandibular surgery alone because OSA is known to be a syndrome that occurs at multiple sites along the airway and not a single area.

Airway Changes with Maxillomandibular Advancement

Maxillomandibular advancement surgery was not always the preferred method to treat OSA. In fact, until 1979, tracheostomy was often the treatment method for OSA patients that could not tolerate other sleep apnea therapies⁴⁸. MMA consists of advancement of the maxilla by a LeFort I osteotomy as well as advancement of the mandibular by a bilateral sagittal split osteotomy. Advancement of upper and lower jaws allows for concurrent advancement of the suprahyoid and velopharyngeal muscle attachments, thereby opening the airway.

According to the literature, MMA has been shown to consistently increase posterior airway space. This increase in airway occurs due to elevation of structures attached to the maxilla, mandible, and hyoid as well causing increased tension on pharyngeal muscles²⁶. However, most of this research has been conducted using lateral cephalometric measurements and these measurements do not take into account the transverse changes in the airway after orthognathic surgery.

Stability of Maxillomandibular Advancement

Maxillomandibular advancement surgery for patients with obstructive sleep apnea usually consists of advancements of 1cm in distance. There have been critics that believe that such large advancements may not be stable. However, long-term follow research has shown that the results of MMA surgery are stable^{27,49-53}. Stability may be due to the advent of rigid internal fixation which helps to secure the skeletal segments during large surgical movements.

Dental Radiographs

Traditional radiographs have limited diagnosis potential since they are only a 2-dimensional perspective. In fact, there many are advocating the use of CBCT imaging in place of a panoramic, lateral cephalometric and periapical radiographs. The radiation dose of a CBCT scan can also be adjusted by using a smaller field of view that would still provide the necessary data, but provide a lower dose of radiation.

Cone Beam Computerized Tomography (CBCT)

Cone beam computed tomography (CBCT) imaging, is a relatively novel approach to imaging. CBCT was first introduced in the 1990s, and is currently in over 3,000 dental offices. The advent of CBCT allowed the use of a 3-dimensional imaging in dentistry with largely reduced radiation exposure, shorter scan times, and less costs when compared to conventional computed tomography used in the medical field⁵⁴. Cone beam scanners obtain their images by

directing x-rays in a divergent cone, thereby acquiring hundreds of images while the scanner revolves around the patient's head. These images are then reconstructed by software programs like Dolphin 3D, in order to obtain a diagnostic quality volumetric image that can then be analyzed.

Figure 8. CBCT scanning technology⁵⁵.

CBCT Image Accuracy

Cone beam computed tomography is a superior imaging technology in of itself due to the fact that it allows for a 3-dimensional representation of anatomic structures. However, there

have been questions raised as to how accurate CBCT images are and if they are comparable to 2-dimensional radiographic techniques.

Several studies have been completed comparing the accuracy of anatomic data obtained from lateral cephalograms and CBCT images. Both studies concluded that CBCT is useful tool for analysis posterior airway space. The authors also found that there was variability in volumetric measurements even though the airway dimensions appeared to be similar in the lateral cephalograms. This suggests that one cannot get true story of airway dimensions from an 2-dimensional image^{17,56}.

In 2007, Moshiri et al. compared the accuracy of linear measurements taken from CBCT images to those measurements taken from traditional cephalometric headfilms. The investigation found that lateral cephalometric images rendered from CBCT data were more accurate than traditional lateral cephalometric headfilms⁵⁷.

Periago et al. studied the accuracy and reliability of linear measurements from cone beam images taken from measurements on human skulls and then reconstructed with an orthodontic volumetric rendering program⁵⁸. The study found that the linear measurements taken on reconstructed 3D images can be different from anatomic dimensions. However, most measurements could be considered to be sufficiently clinically accurate for craniofacial analyses.

Radiation Safety

When it comes to radiation safety and what is a safe dose for any sort of imaging, one should consider the risks and rewards associated with the exposure. Cone beam computed

tomography can have 4 times less radiation exposure than conventional CT imaging, but it is dependent on the adjusted settings for the CBCT machine⁵⁹. For example, less radiation exposure can be achieved if a lower mA and collimation setting is selected for a particular machine⁶⁰. The effective patient dose from a CBCT has been reported as low as 45uSv, but when the settings are modified to give the patient a lower dose, there is often a compromise in the quality of the image produced. As a reference, the average exposure for a full-mouth series of radiographs has been reported to be approximately 150 uSv, which a panoramic radiograph has been detailed to be 54uSv^{61,62}. Therefore, the use of CBCT imaging for 3-dimensional volumetric imaging can be justified for patients with suspected airway compromise as long as the effective dose of the scan is kept as low as reasonably possible.

CBCT Benefits, Limitations, and Applications within Orthodontics

There are many benefits to cone beam tomography when compared to traditional cephalometric radiography. Cephalometric radiography disadvantages include the following: Superimposition of left and right structures, magnification errors, and difficulty in identifying key points (i.e. A point). According to an article by Lenza et al., linear measurements on cephalograms are far less clear than 3-dimensional analysis of similar structures⁶³.

CBCT imaging is becoming more popular in the dental community because it can be advantageous in implant placement, identifying impacted teeth, and skeletal asymmetries just to name a few. Cone beam images are not only 3-dimensional, but also provide an image with no magnification consequently the image is a 1:1 scale. Another benefit of CBCT data is the fact that hard and soft tissue analysis is available at the same time and the operator has the ability to

rotate and view airway from all perspectives^{19,57,64}. An additional and major advantage of cone beam computed tomography when compared to lateral cephalograms is that it allows for detailed assessment and accurate quantitative measurements of cross-sectional area and volume to help identify areas of obstruction.

However, although CBCT is a tremendous tool in evaluating airway parameters, it does have limitations when evaluating the airway. One of the limitations is that it is a static evaluation of a dynamic structure. Another limitation is the fact that airway dimensions have been shown to change depending on the stage of the breathing. Most dental CBCT machines acquire their scans in an upright position. However, the airway volume has been demonstrated to change when a patient is in a supine position⁶⁵. Therefore this is another limitation that should be kept in mind when evaluating airway volume and cross-sectional data.

The Current Question

There is clear evidence that MMA surgery improves airway patency in patients with sleep apnea^{2,9,16,24,26-30,32,51,53,65,66}. However, much of this research was conducted using a 2-dimensional cephalograms. This study determines which specific area of the airway is most significantly impacted by maxillomandibular advancement with counterclockwise rotation of the occlusal plane. This study compares 2-dimensional measurements to 3-dimensional measurements of the airway at certain points to determine if there is a correlation in the results.

CHAPTER 3: EXPERIMENTAL DESIGN AND METHODS

Imaging Protocol

This study is in collaboration with Dr. Mary E. Burns, clinical orthodontist, in New Hope, Pennsylvania. The DICOM files used were de-identified before they were utilized for this study. The cone-beam computer tomography scanner used to take the volumetric images was a Kodak CS 9300.

A total of 28 subjects pre- and post-surgical CBCT scans were evaluated. All of the individuals underwent maxillomandibular advancement with a counterclockwise rotation of the occlusal plane. Although not all patients were diagnosed with obstructive sleep apnea, but did illustrate airway constriction at one or more levels along the posterior airway space (PAS). The average age for the subjects was 35 years +/- 17 years, with a range of 14-63 years.

IRB Approval

Cone-beam images used in this study were reviewed and exempted by the Institutional Review board at West Virginia University (Appendix A).

Methodology

All DICOM files were analyzed using Dolphin 3D Imaging 11.5, licensed to West Virginia University Department of Orthodontics. The 3D volumes were segmented to obtain the clearest representation of the airway and related structures. Orientation of the images were accomplished by using the following planes: 1) the horizontal plane, also known as axial plane, was determined by constructing a line through the lowest border of the infra-orbital rims and, 2) the vertical plane, also known as the mid-sagittal plane, was determined by constructing a line through ANS and the dental midline.

Figure 9. Image Orientation.

Following orientation of the pre- and post- surgical images, the CBCT volume was used to create right lateral cephalograms which were then used for linear cephalometric measurements. The 3D volume was also utilized to find cross-sectional measurements from axial slices taken from the cone-beam images at specific points. Finally, CBCT images were used to find volume measurements at explicit regions along the posterior airway space.

The sites for the posterior airway space assessment were chosen as the landmarks were easily and reproducibly identified on 2-dimensional and 3-dimensional images. Utilization of these references and landmarks allowed for standardized data collection, thus minimizing the chances of invalid calculations. The method used for evaluation of the airway was adapted from an article by Park et al⁴⁴.

Image Analysis for Linear Cephalometric Measurements

The following cephalometric reference points were used to analyze the cephalograms:

- Po (Porion): The most superior point of the external auditory meatus
- Or (Orbitale): The most inferior point of the orbital margin
- PNS: The most posterior point of the hard palate
- CV1: The most anterior inferior point of the anterior arch of the atlas
- CV2: The most anterior inferior point of the body of the 2nd cervical vertebra
- CV3: The most anterior inferior point of the body of the 3rd cervical vertebra

The following cephalometric reference planes were used to analyze the cephalograms:

- FH plane (Frankfort Horizontal): The plane constructed through Po and Or

- PNS Plane: The plane parallel to FH passing through PNS
- CV1 Plane: The plane parallel to FH passing through CV1
- CV2 Plane: The plane parallel to FH passing through CV2
- CV3 Plane: The plane parallel to FH passing through CV3
- Anterior Airway Plane - a vertical plane through PNS, the soft palate, the base of the tongue, and the anterior wall of the pharynx
- Posterior Airway Plane – a vertical plane through the posterior wall of the pharynx

After the planes were constructed, the following measurements were then taken from the cephalograms:

- Airway at PNS – Distance from anterior pharyngeal wall to posterior pharyngeal wall at the level of PNS
- Airway at CV1 – Distance from anterior pharyngeal wall to posterior pharyngeal wall at the level of CV1
- Airway at CV2 – Distance from anterior pharyngeal wall to posterior pharyngeal wall at the level of CV2
- Airway at CV3 - Distance from anterior pharyngeal wall to posterior pharyngeal wall at the level of CV3

Figure 10. Linear Analysis Method.

Image Analysis for Planar (cross-sectional) Measurement

The following reference points were used to analyze the 3D volume:

- Po (Porion): The most superior point of the external auditory meatus
- Or (Orbitale): The most inferior point of the orbital margin
- PNS: The most posterior point of the hard palate
- CV1: The most anterior inferior point of the anterior arch of the atlas
- CV2: The most anterior inferior point of the body of the 2nd cervical vertebra
- CV3: The most anterior inferior point of the body of the 3rd cervical vertebra

The following reference planes were used to analyze the 3D volume:

- FH plane (Frankfort Horizontal): The plane constructed through Po and Or

- PNS Plane: The plane parallel to FH passing through PNS
- CV1 Plane: The plane parallel to FH passing through CV1
- CV2 Plane: The plane parallel to FH passing through CV2
- CV3 Plane: The plane parallel to FH passing through CV3
- Anterior Airway Plane - a vertical plane through PNS, the soft palate, the base of the tongue, and the anterior wall of the pharynx
- Posterior Airway Plane – a vertical plane through the posterior wall of the pharynx

Cross-sectional measurements of the airway were then calculated by using axial slices through PNS, CV1, CV2 and CV3.

Figure 11. Cross-sectional area at the level of PNS

After cross-sectional measurements were taken, the minimal cross-sectional area was also found for each subject. The minimal axial area was calculated by using a specific analysis tool Dolphin 3D version 11.5.

Figure 12. Minimal Axial Area Measurement.

Image Analysis for Volume Measurements

Boundaries to measure posterior airway volume were as follows:

- Anterior - a vertical plane through PNS, the soft palate, the base of the tongue, and the anterior wall of the pharynx
- Posterior - the posterior wall of the pharynx
- Lateral – the lateral walls of the pharynx
- Upper – a horizontal plane passing through PNS
- Lower - a horizontal plane passing through CV3

Volumetric Measurements were calculated by delineating the following planes and then calculating the volume within these regions:

- Total Volume was found by evaluating the region between the planes tangent to PNS and CV3.
- Retropalatal (RPv) volume was found by measuring the volume between the planes tangent to PNS and CV1 and perpendicular to the sagittal plane.
- Oropharyngeal (OPv) volume was found by measuring the volume between the planes tangent to CV1 and CV2 and perpendicular to the sagittal plane.
- Hypopharyngeal (HPv) volume was found by measuring the volume between the plane tangent to CV2 and CV3 and perpendicular to the sagittal plane.

Figure 13. Total Volume Measurement.

Figure 14. Retropalatal Volume Measurement.

Figure 15. Oropharyngeal Volume Measurement.

Figure 16. Hypopharyngeal Volume Measurement.

Method Error

The reliability of this three-dimensional airway analysis is tested by investigating the error in locating and measuring the changes of all landmarks. Ten subjects are analyzed a second time two weeks after the initial tracing. For all variables, differences between the measurements recorded at the first analysis and measurements recorded at the second analysis

are compared for each of the 10 individuals. A matched-pairs reliability test was used to statistically analyze each measurement to establish a coefficient of reliability to determine the degree of reliability of the analysis.

Statistical Analysis

Means were determined for pre-surgical and post-surgical groups. Microsoft Excel 2010 SPSS data analysis tool is used to determine significance of change in airway volume, cross-sectional area and linear measurements after orthognathic surgery. Further analysis will be done with data at a later time.

CHAPTER 4: RESULTS

Method Error Result

The reliability coefficient was found to determine the repeatability of the measures made for the variables in this study. When we have two measurements, the coefficient of reliability is the correlation between the first and second measurements. There is high reliability if the correlation is close to one. For all variables the correlation is 0.99 or 0.98 (Table 1). This means the first and second measurements are in agreement. Therefore, the data collected in this study is consistent and reliable.

Table 1. Reliability Coefficient

Reliability Coefficient			
Pre-op Airway at PNS	0.99	Post-op Airway at PNS	0.98
Pre-op Airway at CV1	0.99	Post-op Airway at CV1	0.99
Pre-op Airway at CV2	0.98	Post-op Airway at CV2	0.98
Pre-op Airway at CV3	0.99	Post-op Airway at CV3	0.99
Pre-op PNS CS Area	0.99	Post-op PNS CS Area	0.99
Pre-op CV1 CS Area	0.99	Post-op CV1 CS Area	0.99
Pre-op CV2 CS Area	0.99	Post-op CV2 CS Area	0.99
Pre-op CV3 CS Area	0.99	Post-op CV3 CS Area	0.99
Pre-op Min CS Area	0.99	Post-op Min CS Area	0.99
Pre-op Total Area	0.99	Post-op Total Area	0.99
Pre-op RP Volume	0.99	Post-op RP Volume	0.99
Pre-op OP Volume	0.99	Post-op OP Volume	0.99
Pre-op HP Volume	0.99	Post-op HP Volume	0.99
Pre-op Total Volume	0.99	Post-op Total Volume	0.99

Airway Change: All subjects

When all subjects were grouped together the p-value for the change in all variables was <0.001 (Table 2). This indicates that there was a statistically significant change in all variables regardless of the method used to evaluate pre- and post-surgery changes.

Table 2. Airway Changes for all subjects (n=28).

All Subjects N=28						
Variable Name	Pre-Op Mean	Post-Op Mean	Difference	SD	p-value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	22.61	25.87	3.26	4.16	0.0003	*
Airway at CV1	8.81	14.18	5.37	2.54	0.0001	*
Airway at CV2	9.5	13.67	4.18	3.41	0.0001	*
Airway at CV3	12.61	15.36	2.75	2.86	0.0001	*
Axial CSA (mm²)						
PNS	536.44	627.5	91.05	109.16	0.0001	*
CV1	215.28	388.68	173.4	94.52	0.0001	*
CV2	186.46	320.4	133.94	106.46	0.0001	*
CV3	251.42	309.46	58.04	72.19	0.0002	*
Min Axial Area	116.43	237.75	121.32	85.98	0.0001	*
Total Area	609.54	805.34	195.8	128.74	0.0001	*
Pharyngeal Volume (mm³)						
Total	14856.8	22841.9	7985.1	4857.17	0.0001	*
Retropalatal	5953.46	7704.74	1751.28	1522.2	0.0001	*
Oropharyngeal	5222.89	9925.83	4702.94	2887.89	0.0001	*
Hypopharyngeal	3685	5360.44	1675.44	1678.46	0.0001	*
* = statistically significant NS = Not significant						

Airway Change in Younger vs. Older Patients.

The subjects were also divided according to age. Two groups were formed and each group had an n=14. One group was identified as the younger age group while the other was called the older age group. The younger age group consisted of individuals whose age ranged from 14-39. The older age group included subjects that were between the ages of 40-80 years. The p-value for both groups in all variables was <0.05 (table 3 and 4). This indicates that when the subjects were treated with maxillomandibular advancement surgery, there was a statistically significant change in all variables regardless of the age of the patients.

Table 3. Younger Age Group (n=14).

Younger (14-39) N=14						
Variable Name	Pre-Op Mean	Post-Op Mean	Difference	SD	p-value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	22.7	25.83	3.2	4.75	0.026	*
Airway at CV1	10.47	16.04	5.57	2.09	0.0001	***
Airway at CV2	10.16	14.02	3.86	3.25	0.0007	***
Airway at CV3	12.97	15.17	2.2	3.14	0.02	*
Axial CSA (mm²)						
PNS	561.77	679.71	117.94	121.98	0.0031	**
CV1	273.59	464.51	190.92	107.04	0.0001	***
CV2	220.13	342.54	122.41	83.63	0.0001	***
CV3	252.94	304.76	51.82	69.45	0.0152	*
Min Axial Area	142.19	272.96	130.77	85.3	0.0001	***
Total Area	669.21	847.69	178.48	125.94	0.0001	***
Pharyngeal Volume (mm³)						
Total	17194.7	25280.5	8085.73	4769.42	0.0001	***
Retropalatal	6620.99	8526.59	1905.61	1813.28	0.0017	**
Oropharyngeal	6609.91	11246.5	4636.58	2773.13	0.0001	***
Hypopharyngeal	4101.76	5724.87	1623.11	1622.01	0.0025	**
* = p-value < 0.05 ** = p-value < 0.01 *** = p-value < 0.001 NS = Not significant						

Table 4. Older Age Group (n=14).

Older (40-79)						
N=14						
Variable Name	Pre-Op Mean	Post-Op Mean	Difference	SD	p-value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	22.53	25.83	3.31	3.62	0.0047	**
Airway at CV1	7.15	12.33	5.18	2.96	0.0001	***
Airway at CV2	8.83	13.32	4.49	3.63	0.0005	***
Airway at CV3	12.25	15.55	3.3	2.51	0.0003	***
Axial CSA (mm²)						
PNS	511.11	575.28	64.16	91.26	0.02	*
CV1	156.97	312.84	155.86	80.18	0.0001	***
CV2	152.8	298.26	145.46	127.57	0.0009	***
CV3	249.91	314.16	64.25	76.93	0.0081	**
Min Axial Area	90.66	202.54	111.87	88.83	0.0004	***
Total Area	549.86	762.99	213.13	133.91	0.0001	***
Pharyngeal Volume (mm³)						
Total	12518.8	20403.3	7884.46	5121.58	0.0001	***
Retropalatal	5285.94	6882.89	1596.95	1213.68	0.0003	***
Oropharyngeal	3835.87	8605.17	4769.3	3101.87	0.0001	***
Hypopharyngeal	3268.24	4996	1727.76	1792.85	0.0032	**
* = p-value < 0.05 ** = p-value < 0.01 *** = p-value < 0.001 NS = Not significant						

Changes in Airway by MMA with or without Genioplasty

The subjects were divided into two groups depending on whether or not they received a genioplasty with their MMA surgery. The group that only had MMA surgery was the larger of the two groups with an n=17. While the group that did have MMA surgery with a genioplasty had an n=11. The p-value for both groups in all variables was <0.05 (table 5 and 6). This indicates that MMA with or without a genioplasty produces a statistically significant change in airway volume, cross-sectional and planar measurements.

Table 5. Subjects with MMA without Genioplasty.

MMA w/o Genioplasty N=17						
Variable Name	Pre-Op Mean	Post-Op Mean	Difference	SD	p-value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	22.74	25.66	2.93	4.57	0.018	*
Airway at CV1	8.96	13.99	5.03	2.49	0.0001	***
Airway at CV2	9.03	13.7	4.66	3.75	0.0001	***
Airway at CV3	13.35	15.79	2.45	2.76	0.0023	**
Axial CSA (mm²)						
PNS	570.66	644.71	74.05	85.39	0.0025	**
CV1	235.85	403.01	167.17	89.01	0.0001	***
CV2	202.29	330.38	128.09	116.8	0.0003	***
CV3	274.97	323.24	48.27	60.11	0.0044	**
Min Axial Area	129.54	240.75	111.21	82.13	0.0001	***
Total Area	618.2	797.34	179.14	111.44	0.0001	***
Pharyngeal Volume (mm³)						
Total	15968.9	23568.3	7599.34	4173.57	0.0001	***
Retropalatal	6276.87	7796.98	1520.11	1310.03	0.0002	***
Oropharyngeal	5691.42	10332.2	4640.81	2646.66	0.0001	***
Hypopharyngeal	4097.42	5679.24	1581.82	1735.54	0.0017	**
* = p-value < 0.05 ** = p-value < 0.01 *** = p-value < 0.001 NS = Not significant						

Table 6. Subjects with MMA with Genioplasty

MMA w/ Genioplasty N=11						
Variable Name	Pre-Op Mean	Post-Op Mean	Difference	SD	p-value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	22.42	26.18	3.76	3.51	0.0053	**
Airway at CV1	8.57	14.48	5.9	2.62	0.0001	***
Airway at CV2	10.21	13.63	3.42	2.72	0.002	**
Airway at CV3	11.46	14.69	3.22	3.02	0.0056	**
Axial CSA (mm²)						
PNS	483.56	600.9	117.34	138.83	0.019	*
CV1	183.5	366.52	183.02	106.13	0.0002	***
CV2	162.01	304.99	142.98	92.93	0.0005	***
CV3	215.03	288.16	73.13	88.71	0.021	*
Min Axial Area	96.17	233.12	136.95	93.39	0.0007	***
Total Area	596.14	817.7	221.55	153.95	0.0008	***
Pharyngeal Volume (mm³)						
Total	13138	21719.2	8581.27	5931.78	0.0007	***
Retropalatal	5453.65	7562.19	2108.55	1810.74	0.0031	**
Oropharyngeal	4498.79	9297.75	4798.95	3360.6	0.0008	***
Hypopharyngeal	3047.63	4867.74	1820.11	1658.01	0.0045	**
* = p-value < 0.05 ** = p-value < 0.01 *** = p-value < 0.001 NS = Not significant						

Change in Airway in Males vs. Females

The subjects were also divided according to gender. The female group was the larger of the two groups with an n=19, while the male group consisted of an n=9. The p-value for both groups in all variables was <0.05 , except for except for the cephalometric airway space at the level of CV3 (table 7 and 8). The lack of significance at the level of CV3 on the cephalogram may be due to the small number of males in this study sample.

Table 7. Male Subjects (n=9)

Male N=9						
Variable Name	Pre-Op Mean	Post- Op Mean	Difference	SD	p- value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	23.45	27.56	4.11	5.16	0.04	*
Airway at CV1	9.82	16.24	6.42	2.19	0.0001	***
Airway at CV2	10.28	14.61	4.33	2.88	0.002	**
Airway at CV3	11.94	15.06	3.12	4.2	0.057	NS
Axial CSA (mm²)						
PNS	574.2	700.03	125.83	118.65	0.013	*
CV1	275.96	504.24	228.29	84.24	0.0001	***
CV2	230.32	389.78	159.46	69.99	0.0001	***
CV3	254.03	323.21	69.18	82.86	0.04	*
Min Axial Area	141.32	296.04	154.72	91.5	0.001	**
Total Area	731.92	962.06	230.13	128.64	0.0007	***
Pharyngeal Volume (mm³)						
Total	18791.8	29680	10888.2	4210.14	0.0001	***
Retropalatal	7530.56	9985.23	2454.68	1446.39	0.0009	***
Oropharyngeal	7013.99	13566.8	6552.77	2750.34	0.0001	***
Hypopharyngeal	4279.67	6410.53	2130.87	1775.52	0.007	**
* = p-value < 0.05 ** = p-value < 0.01 *** = p-value < 0.001 NS = Not significant						

Table 8. Females (n=19)

Female N=19						
Variable Name	Pre-Op Mean	Post-Op Mean	Difference	SD	p- value	Sig
Linear Cephalometric Measurements (mm)						
Airway at PNS	22.21	25.07	2.85	3.66	0.0034	**
Airway at CV1	8.33	13.21	4.88	2.57	0.0001	***
Airway at CV2	9.13	13.23	4.1	3.7	0.0001	***
Airway at CV3	12.93	15.5	2.58	2.05	0.0001	***
Axial CSA (mm²)						
PNS	518.56	593.14	74.58	103.61	0.0057	**
CV1	186.42	333.93	147.39	89.57	0.0001	***
CV2	165.69	287.54	121.85	119.78	0.0003	***
CV3	250.18	302.94	52.76	68.35	0.0035	**
Min Axial Area	104.64	210.14	105.5	80.9	0.0001	***
Total Area	551.56	731.11	179.54	129.02	0.0001	***
Pharyngeal Volume (mm³)						
Total	12992.8	19602.7	6609.95	4615.28	0.0001	***
Retropalatal	5206.42	6624.51	1418.09	1476.88	0.0006	***
Oropharyngeal	4374.47	8201.18	3826.71	2574.23	0.0001	***
Hypopharyngeal	3403.32	4863.02	1459.7	1634.58	0.0011	**
* = p-value < 0.05 ** = p-value < 0.01 *** = p-value < 0.001 NS = Not significant						

CHAPTER 5: DISCUSSION

Airway Change: All subjects

When all subjects were grouped together the p-value for the change in all variables was <0.001 . This indicates that there was a statistically significant change in all variables regardless of the method used to evaluate pre- and post-surgery changes. It also suggests that although CBCT is a valuable tool to evaluate airway change, cephalometric radiographs can be used to determine whether change in PAS is significant when it pertains to maxillomandibular advancement surgery. In fact, this finding is in agreement with an article by Riley et al., which illustrated a strong correlation between cephalometric PAS measurements and volume⁴⁹.

The results of statistically significant change in airway dimensions at all levels, agrees with recent articles regarding increase in PAS after MMA surgery. The greatest change in the linear and planar measurements was at the level of CV1. The greatest change in volume measurement (excluding total volume) was the oropharyngeal volume. These findings are consistent with Tso et al., which affirm that the oropharyngeal portion is the narrowest region of the airway when a patient is awake and sitting up right⁶⁷.

According to Ogawa et al., the location of the smallest cross-sectional area in patients with OSA was below the occlusal plane in greater than 70% of the subjects⁶⁸. The current study found that the majority of the patients had their min axial area located below the occlusal plane. This indicates that although not all patients were clinically diagnosed with OSA, they will likely benefit from MMA.

Airway Change in Younger vs. Older Subjects

The subjects were also divided according to age. Two groups were formed and each group had an n=14. One group was identified as the younger age group while the other was called the older age group. The younger age group consisted of individuals whose age ranged from 14-39. The older age group included subjects that were between the ages of 40-80 years. The p-value for both groups in all variables was <0.001 . This indicates that when the subjects were treated with maxillomandibular advancement surgery, there was a statistically significant change in all variables regardless of the age of the patients.

As mentioned, statistically significant differences were not seen between either of the age groups. However, the older group consistently had smaller mean pre-op values for all variables that were analyzed. This observation is in agreement with a recent article by Schendel et al., which states that “as individuals grow, the total volume, length, area, and index all increase until age 20, then remain relatively flat until age 50, when they all begin to decrease dramatically”⁶⁹. Schendel also established that most of the total volume decrease was represented by a decrease in the smallest cross-sectional area with age as the airway became smaller which was also seen in this study.

Changes in Airway in Groups with or without Genioplasty

The subjects were divided into two groups according on whether or not they received a genioplasty with their MMA surgery. The group that only had MMA surgery was the larger of the two groups with an n=17. While the group that did have MMA surgery with a genioplasty

had an n=11. The p-value for both groups in all variables was <0.05 . Therefore there was a significant change in both groups regardless of whether a genioplasty was a part of the surgical procedure. This finding is in concert with an article by Susarla et al., which found that there was no difference in PAS between patients that had MMA alone compare to those that had MMA with a genioplasty⁷⁰.

Change in Airway in Males vs. Females

The subjects were also divided according to gender. The female group was the larger of the two groups with an n=19, while the male group consisted of an n=9. The p-value for both groups in all variables was <0.05 , except for except for the cephalometric airway space at the level of CV3. The lack of significance at the level of CV3 on the cephalogram may be due to the small number of males in this study sample.

Limitations of Study

Limitations of the study included differences in medical history, gender, and ethnicity among the subjects. Orthognathic surgery has been known to have relapse tendency so another limitation of the study was that there was not long-term follow-up data to assess the long-term stability of the surgical treatment. Although CBCT is a tremendous tool in evaluating airway parameters, it does have limitations which include:

- 1) It is a static evaluation of a dynamic structure
- 2) Airway dimensions have been shown to change depending on the stage of the breathing

- 3) Scans were taken in an upright position. The airway volume has been demonstrated to change when a patient is in a supine position.

CHAPTER 6: SUMMARY AND CONCLUSIONS

Summary

The rationale for this study is to gain a better understanding of the alteration in linear, planar and volumetric posterior airway space following double-jaw advancement surgery with a counter-clockwise rotation of the occlusal plane. In addition, this study will investigate whether there is a correlation between 2-dimensional cephalometric and 3-dimensional cross-sectional measurements at specific sites along the airway.

This study was in collaboration with New Hope Orthodontics, which is the private practice of Dr. Mary E. Burns. A total of 28 subjects pre- and post-surgical CBCT scans were evaluated. All of the individuals underwent a maxillomandibular advancement with a counterclockwise rotation of the occlusal plane. All DICOM files were analyzed using Dolphin 3D Imaging 11.5, licensed to West Virginia University Department of Orthodontics. The CBCT volume was used to create right lateral cephalograms which were then used for linear cephalometric measurements. The 3D volume was also utilized to find cross-sectional measurements from axial slices taken from the cone-beam images at specific points: PNS, CV1, CV2 and CV3. Finally, CBCT images were used to find volume measurements at explicit regions along the posterior airway space. Data was analyzed using a matched-pair test.

Based on results discussed in Chapter IV, the following null hypotheses were rejected:

1. There is no difference in total airway volume pre- and post- MMA surgery.
2. There is no difference in airway volume pre- and post-MMA surgery in the following areas:
  - ❖ Retropalatal
  - ❖ Oropharyngeal
  - ❖ Hypopharyngeal
3. There is no significant difference in cross-sectional area pre- and post MMA surgery at the following levels
  - ❖ PNS
  - ❖ CV1
  - ❖ CV2
  - ❖ CV3
4. There is no correlation between cephalometric linear measurements and 3-dimensional cross-sectional measurements
  - ❖ The maxillomandibular advancement procedure with or without genioplasty illustrated great increases in posterior airway space in both 2-dimensional and 3-dimensional analyses.
  - ❖ However, more information was available in regards to site of airway obstruction when utilizing the 3D data in comparison to 2D.

- ❖ Therefore, the null hypothesis regarding no correlation in 3D vs. 2D analysis was rejected.

Conclusions

Maxillomandibular advancement surgery with or without genioplasty illustrated great increases in posterior airway space in both 2-dimensional and 3-dimensional analyses. However, more information was available in regards to site of airway obstruction when utilizing the 3D data in comparison to 2D. Patients with obstructive sleep apnea should be presented with the option of MMA surgery as a treatment option if CPAP is not tolerated.

CHAPTER 7: RECOMMENDATIONS FOR FUTURE RESEARCH

With the rate of obesity continuing to rise in the United States, OSA is a syndrome that is only going to increase with its prevalence. Possible areas of research could include long-term follow data of the current study. This would help determine the stability of the skeletal movements. Another possible study could evaluate airway length and cross-sectional lateral and anteroposterior measurements pre- and post-surgery. This would help further identify the segment of the airway that increases the most after MMA surgery. In addition this will aid to determine which group of individuals will benefit the most dependent on where their region of most constriction occurs.

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APPENDIX

Acknowledgement Letter Not Human Subject Research NHR

To	Peter Ngan
From	WVU Office of Research Integrity and Compliance
Approval Period	01/23/2014 Expiration Date 01/22/2019
Subject	Not Human Subject Research Acknowledgment
Protocol Tracking	1401168620
Title	Total Airway Volume Comparison Pre- and Post-Orthognathic Surgery

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Thank you for your submission to the West Virginia University Institutional Review Board IRB.

It has been determined that your project does not meet the definition of human subject research for the following reasons

- In order to be considered human subject research, individually identifiable private information must be obtained or used in the research. If there is no individually identifiable private information involved, the project is not human subject research and does not require being submitted to the Office of Research Integrity & Compliance. Private information must be individually identifiable (i.e., the identity of the subject is or may be readily ascertained by the investigator or someone else associated with the information) in order to constitute research involving human subjects.

If you have any questions, please contact the IRB at 304 293 7073.

Thank you.

A handwritten signature in black ink that reads 'Lilo Ast'.

Board Designee Lilo Ast

Letter Sent By Lilo Ast on 01/23/2014 at 20:08:45-05:00

CURRICULUM VITAE

Deepa Vyas was born in Ahmedbad, India and moved to Texas when she was 1 ½ years old. She is the daughter of Rekha and Kirit Vyas and sister to Pranav and Charul Vyas. Deepa was raised in Friendswood, Texas, a suburb of Houston. While attending the University of Texas at Austin, she obtained a degree in Biochemistry. After graduating college, she participated in the national service program AmeriCorps for 6 months.

She then attended dental school at Boston University School of Dental Medicine and received a D.M.D. in 2011. While at Boston University, Deepa was involved in the following organizations: DMD 2011 Class Officer, American Student Dental Association (ASDA), Student National Dental Association, Hispanic Dental Association, Alpha Omega Fraternity, ASDA Big Brothers, Big Sisters, American Association of Women Dentists, Student Research Group, and Orthodontic Study Club. In addition to being actively involved in her community she was also on the dean's list every semester and graduated the top of her class. Following dental school Deepa started her orthodontic residency, under the guidance of Chairman Dr. Peter Ngan, in July 2011 and will graduate April 2014 with an M.S. degree and a certificate in Orthodontics.